



## VERIFICATION OF TRANSLATION

I, Woo-Hyun HWANG, of Suite 1810, Hwanghwa Bldg., 832-7, Yoeksam-dong, Gangnam-gu, Seoul, Republic of Korea hereby declare that I am knowledgeable in the English and Japanese languages, and that to the best of my knowledge the attached document is true and complete English translation of the patent application of Japanese patent Application No. 2003-317165.

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Signature



# **ORGANIC ELECTROLUMINESCENCE DEVICE AND METHOD OF FABRICATING THE SAME**

Japanese Application No. 2003-317165

Filed on October 17, 2000



# ORGANIC ELECTROLYUMINESCENCE DEVICE AND METHOD OF FABRICATING THE SAME

## WHAT IS CLAIMED IS:

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1. An organic EL device comprising a main element portion in which an anode formed of a transparent electrode, an organic layer including at least an organic emission layer, and a cathode are sequentially stacked on a transparent insulating substrate, and a cap for encapsulating the main element portion; and  
10 characterized in that oxygen is contained at an interface between the organic layer and the cathode.

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2. An organic EL device comprising a main element portion in which an anode formed of a transparent electrode, an organic layer including at least an organic emission layer, and a cathode are sequentially stacked on a transparent insulating substrate, and a cap for encapsulating the main element portion; and  
characterized in that the cathode is composed of a first cathode and a second cathode, and oxygen is contained at an interface between the organic layer and the cathode.

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3. An organic EL device comprising a main element portion in which an anode formed of a transparent electrode, an organic layer including at least an organic emission layer, and a cathode are sequentially stacked on a transparent insulating substrate, and a cap for encapsulating the main element portion; and

characterized in that the cathode is composed of a plurality of cathodes,  
and an amount of oxygen contained in a first cathode in contact with the organic  
layer among the plurality of cathodes is larger than that in the rest cathodes  
including a second cathode not in contact with the organic layer among the  
5 plurality of cathodes.

4. The organic EL device as recited in any one of claim 1 to claim 3,  
wherein the cathode has a layer thickness of about 20nm to 100nm.

10 5. A method of fabricating an organic EL device comprising a main  
element portion in which an anode formed of a transparent electrode, an  
organic layer including at least an organic emission layer, and a cathode are  
sequentially stacked on a transparent insulating substrate, and a cap for  
encapsulating the main element portion; and

15 characterized in that the transparent insulating substrate in which the  
main element portion is already formed is disposed in a vacuum device before  
the encapsulation, and oxygen is contained at an interface between the organic  
layer and the cathode while the vacuum device maintains its internal vacuum  
state.

20 6. A method of fabricating an organic EL device comprising a main  
element portion in which an anode formed of a transparent electrode, an  
organic layer including at least an organic emission layer, and a plurality of  
cathodes are sequentially stacked on a transparent insulating substrate, and a

cap for encapsulating the main element portion, the method comprising:

forming a transparent conductive layer on the transparent insulating substrate, and then patterning the transparent conductive layer in a desired shape to form the anode;

5 disposing the transparent insulating substrate on which the anode is already formed within a vacuum device, and stacking the organic layer and a first cathode among the plurality of cathodes on the anode in a vacuum atmosphere;

10 introducing an oxygen gas into the vacuum device while maintaining the vacuum state to have the oxygen gas in contact with the first cathode;

stacking the rest cathodes including a second cathode among the plurality of cathodes on the first cathode in the vacuum atmosphere to form the main element portion; and

encapsulating the main element portion with the cap.

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7. The method as recited in claim 5 or 6, wherein the cathode has a layer thickness of about 20nm to 100nm.

20 8. The method as recited in claim 6 or 7, wherein the oxygen gas is introduced to have an oxygen partial pressure of  $2 \times 10^{-4}$  to  $1 \times 10^{-1}$  Pa within the vacuum device.

9. The method as recited in any one of claim 5 to claim 8, wherein the vacuum device includes a vacuum deposition device.

## **BACKGROUND OF THE INVENTION**

### 1. Field of the Invention

The present invention relates to an organic electroluminescence (EL) device and method of fabricating the same and, more particularly, to an organic EL device in which a main element portion is formed which contains oxygen at an interface between a cathode and an organic layer containing at least an organic emission layer, and method of fabricating the same.

### 2. Description of the Related Art

An organic EL device has been developed as one kind of EL devices which are used in a display device such as information equipment. FIG. 10 is a schematic view showing a structure of a typical organic EL device known in the prior art. As shown in FIG. 10, the organic EL device includes a transparent insulating substrate 51 formed of glass or the like, an anode (a lower electrode) 52 formed of a transparent conductive material such as an indium tin oxide (ITO) layer formed on the transparent insulating substrate 51, a hole transport layer 53 formed on the anode 52, an organic emission layer 54 formed on the hole transport layer 53, a cathode (an upper electrode) 55 formed of an AlLi alloy on the organic emission layer 54, and a cap 57 formed of glass and mounted by means of an encapsulation resin 56 so as to cover a main element portion on the transparent insulating substrate 51, wherein the main element portion is composed of the anode 52, the hole transport layer 53, the organic emission layer 54, and the cathode 55.

For example, a ultra-violet (UV) curing resin is employed as the encapsulation resin, and light including the UV is irradiated on the encapsulation resin from a light source to thereby carry out curing for the encapsulation.

However, the organic EL device often has an incomplete interface  
5 between the cathode and the organic emission layer so that incomplete defects are resultantly present. These defects mean that an impurity level is formed due to lattice defects or the like at a portion where the interface level should be generated, so that an inevitable path other than a path which should be formed becomes produced to have a leakage current increased due to the presence of  
10 the defect. In addition, there might occur a short circuit between the cathode and the anode. As a result, the characteristic of the organic EL device becomes unstable and the frequency of defect occurrence becomes increased.

In this case, a complete interface means that there exists no level derived from the defect in the interface level of the interface between the  
15 organic emission layer and the cathode, electrons may be readily injected by the thermally excited current which is known in the semiconductor field, or the level for tunneling is stably present. On the contrary, the incomplete interface means that a plurality of interface levels are repeatedly formed and lost due to the defects and there occurs a difference in the injection property. As a result,  
20 it is required that the interface between the organic emission layer and the cathode is complete and a stable interface level is formed in the organic EL device. By means of this configuration, the increase of leakage current may be suppressed and the short circuit problem between the cathode and the anode may be avoided, so that the characteristic of the organic EL device may be

stabilized.

In this case, in order to implement the stabilization of the characteristic of the organic EL device in the prior art, there is known an organic EL device which allows an element portion including an organic emission layer to be encapsulated within an oxidizing atmosphere, for example, and Japan Patent Laid-Open Hei 11(1999) – 312580 is disclosed for the same. As shown in FIG. 11, the organic EL device includes a glass substrate 61, an anode 62 formed of ITO on the glass substrate 61, an organic layer 63 formed on the anode 62 and formed of a stacked layer composed of a hole transport material and an emission layer, a cathode 64 formed on the organic layer 63 and formed of a metal such as a stacked layer composed of MgAg, LiF and Al, and a housing 66 encapsulated by a resin 65 formed of a UV curing resin or the like so as not to be in contact with the element portion (namely, the anode 62, the organic layer 63, and the negative layer 64).

In this case, a gas containing an oxidizing gas is filled within the encapsulated space, in particular, a gas mixed with an oxidizing gas ( $O_2$ ,  $N_2O$  or the like) and a non-oxidizing gas ( $N_2$ , Ar, He or the like) is employed, and the concentration of the oxidizing gas is set in a range of 0.1% to 20%. The filling of the mixed gas is carried out such that the glass substrate 61 having the element portion is transported from a layer formation chamber to a pre-evacuation chamber in which the housing 66 is already disposed in a vacuum state, the mixed gas is then introduced into the pre-evacuation chamber until it reaches the atmospheric pressure, and the encapsulation resin is cured by the UV lamp to encapsulate the housing 66.



By means of the above-mentioned structure, it is described that particles are oxidized by the oxidizing gas to be an insulating layer even when the anode 62 and the cathode 64 become a short circuit due to the particles, so that the insulating property between these two electrodes 62 and 64 is restored  
5 and the lifetime of the elements is enhanced.

However, in the organic EL device and method of fabricating the same described in Japan Patent Laid-Open Hei 11(1999) – 312580, only a short circuit between the anode and the cathode is taken into consideration, so that it is difficult to keep the throughput for the device fabrication not to be lowered  
10 and to obtain a high rectification ratio.

In other words, according to the above-mentioned disclosure, the gas mixed with the oxidizing gas and the non-oxidizing gas is introduced before encapsulation so that the particles present between the anode 62 and the cathode 64 are oxidized by the oxidizing gas to enhance the lifetime of the elements. In this case, the cathode 64 of the organic EL device has a thick  
15 thickness of 180nm as described in the paragraph [0025], so that the rectification ratio is not highly taken due to the thick cathode 64. Accordingly, in order to take a high rectification ratio, the thickness of the cathode 64 needs to be thin, which inevitably causes the fabrication yield of the organic EL device  
20 to be deteriorated and the throughput to be lowered.

### **SUMMARY OF THE INVENTION**

The present invention, therefore, solves aforementioned problems associated with conventional devices by providing an organic EL device which

does not lower the throughput for the device fabrication and obtains a high rectification ratio, and method of fabricating the same.

In an exemplary embodiment of the present invention, an organic EL device includes a main element portion in which an anode formed of a transparent electrode, an organic layer including at least an organic emission layer, and a cathode are sequentially stacked on a transparent insulating substrate, and a cap for encapsulating the main element portion, and is characterized in that oxygen is contained at an interface between the organic layer and the cathode.

In another exemplary embodiment of the present invention, an organic EL device includes a main element portion in which an anode formed of a transparent electrode, an organic layer including at least an organic emission layer, and a cathode are sequentially stacked on a transparent insulating substrate, and a cap for encapsulating the main element portion, and is characterized in that the cathode is composed of a first cathode and a second cathode, and oxygen is contained at an interface between the organic layer and the cathode.

In yet another exemplary embodiment of the present invention, an organic EL device includes a main element portion in which an anode formed of a transparent electrode, an organic layer including at least an organic emission layer, and a cathode are sequentially stacked on a transparent insulating substrate, and a cap for encapsulating the main element portion, and is characterized in that the cathode is composed of a plurality of cathodes, and an amount of oxygen contained in a first cathode in contact with the organic layer

among the plurality of cathodes is larger than that in the rest cathodes including a second cathode not in contact with the organic layer among the plurality of cathodes.

The invention claimed in the claim 4 is directed to the organic EL device  
5 claimed in claim 1, 2, or 3, and is characterized in that the cathode has a layer thickness of about 20nm to 100nm.

In yet another exemplary embodiment of the present invention, a method of fabricating an organic EL device having a main element portion in which an anode formed of a transparent electrode, an organic layer including at  
10 least an organic emission layer, and a cathode are sequentially stacked on a transparent insulating substrate, and a cap for encapsulating the main element portion, and is characterized in that the transparent insulating substrate in which the main element portion is already formed is disposed in a vacuum device before the encapsulation, and oxygen is contained at an interface between the  
15 organic layer and the cathode while the vacuum device maintains its internal vacuum state.

In yet another exemplary embodiment of the present invention, a method of fabricating an organic EL device having a main element portion in which an anode formed of a transparent electrode, an organic layer including at  
20 least an organic emission layer, and a plurality of cathodes are sequentially stacked on a transparent insulating substrate, and a cap for encapsulating the main element portion, the method includes: forming a transparent conductive layer on the transparent insulating substrate, and then patterning the transparent conductive layer in a desired shape to form the anode; disposing

the transparent insulating substrate on which the anode is already formed within a vacuum device, and stacking the organic layer and a first cathode among the plurality of cathodes on the anode in a vacuum atmosphere; introducing an oxygen gas into the vacuum device while maintaining the vacuum state to have the oxygen gas in contact with the first cathode; stacking the rest cathodes including a second cathode among the plurality of cathodes on the first cathode in the vacuum atmosphere to form the main element portion; and encapsulating the main element portion with the cap.

The invention claimed in the claim 7 is directed to the method as recited in claim 5 or 6, and is characterized in that the cathode has a layer thickness of about 20nm to 100nm.

The invention claimed in the claim 8 is directed to the method as recited in claim 6 or 7, and is characterized in that the oxygen gas is introduced to have an oxygen partial pressure of  $2 \times 10^{-4}$  to  $1 \times 10^{-1}$  Pa within the vacuum device.

The invention claimed in the claim 9 is directed to the method as recited in any one of claim 5 to claim 8, and is characterized in that a vacuum deposition device is employed as the vacuum device.

### **DETAILED DESCRIPTION OF THE INVENTION**

The present invention will now be described more fully hereinafter with reference to the accompanying drawings, in which preferred embodiments of the invention are shown.

FIG. 1 is a cross-sectional view showing a structure of an organic EL device in accordance with one embodiment of the present invention, FIG. 2a to

2d are process flow diagrams showing a method of fabricating the organic EL device in a process order, FIG. 3 is a schematic view showing a structure of a vacuum deposition device which is used for main steps of the method of fabricating the organic EL device, FIG. 4 is a view showing the rectification characteristic of the organic EL device, and FIG. 5 is a view showing the rectification characteristic of the comparative example of FIG. 4.

As shown in FIG. 1, the organic EL device 10 of the present embodiment includes a transparent insulating substrate 1 formed of glass or the like, an anode 2 formed of a transparent conductive material such as ITO on the transparent insulating substrate 1, a hole transport layer 3 formed of  $\alpha$ -NPD or the like on the anode 2, an organic emission layer 4 formed of Alq3 or the like on the hole transport layer 3, a first cathode 5A formed of an AlLi alloy and having a thickness of about 20 to 100nm on the organic emission layer 4, a second cathode 5B formed of Al or the like on the first cathode 5A through an oxygen-containing layer formed on a surface of the first cathode 5A, and a cap 7 formed of glass or the like and mounted by means of an encapsulation resin 6 so as to cover a main element portion on the transparent insulating substrate 1 including the main element portion in which the anode 2, the hole transport layer 3, the organic emission layer 4, the first cathode 5A, and the second cathode 5B are already formed.

According to the organic EL device 10 of the present embodiment, oxygen is contained at an interface between the organic emission layer 4 and the first cathode 5A to bury defects present at the interface, so that an unstable level becomes stable to be a complete level. As a result, the increase of leak

current may be suppressed and the short circuit between the cathode and the anode may be avoided, thereby allowing the characteristic of the organic EL device to be stabilized.

In addition, a thick cathode composed of the first cathode 5A and the second cathode 5B may be devised to reduce interconnection line resistance. Accordingly, the brightness non-uniformity during emission may be suppressed.

Next, a method of fabricating the organic EL device will be described in a process order with reference to FIG. 2.

As shown in FIG. 2a, ITO is first formed on a transparent insulating substrate 1 such as a sufficiently cleaned glass substrate to have a thickness of about 150nm as a transparent conductive layer by means of a sputtering method. The substrate 1 is cleaned using Iso-Propyl Alcohol (IPA) and pure water, which is subjected to ultrasonic wave cleaning using IPA and then cleaned using a UV ozone cleaner to thereby remove a residual organic material. The ITO is then patterned by a well known photolithography process so as to have an emission area corresponding to 2mm<sup>2</sup> in an EL element to thereby form an anode 2.

A hole transport layer 3 and an organic emission layer 4 are sequentially formed on the anode 2 as shown in FIG. 2b. Formation of the hole transport layer 3 and the organic emission layer 4 is as follows.

First, a boat (second boat) formed of molybdenum in which 100mg of  $\alpha$ -NPD(N, N'-diphenyl)-N, N'-bis(1-naphthyl)-(1, 1'-biphenyl)-(4, 4'-diamine) is supplied as a hole transport material is disposed within a vacuum deposition device so as to be respective evaporation sources. The substrate 1

is then disposed within the vacuum deposition device, and inside of the vacuum deposition device is evacuated until the degree of vacuum reaches  $2 \times 10^{-4}$  Pa, and a first boat is heated at the point of time that it reaches  $2 \times 10^{-4}$  Pa. The heating temperature is controlled until  $\alpha$ -NPD within the first boat reaches a constant evaporation velocity of 0.3nm/sec, a shutter mounted on an upper position of the vacuum deposition device is then opened to start formation of  $\alpha$ -NPD, and is closed at the point of time that the layer thickness of  $\alpha$ -NPD reaches about 50nm, thereby terminating the formation of  $\alpha$ -NPD.

Similarly, the heating temperature is controlled until Alq3 within the second boat reaches a constant evaporation velocity of 0.3nm/sec, a shutter mounted on an upper position of the vacuum deposition device is then opened to start formation of Alq3, and is closed at the point of time that the layer thickness of Alq3 reaches about 55nm, thereby terminating the formation of Alq3.

As a result, the hole transport layer 3 formed of  $\alpha$ -NPD and the organic emission layer 4 formed of Alq3 are formed on the anode 2.

Next, the substrate 1 is transported into another vacuum deposition device 20 which is connected to the above-mentioned vacuum deposition device and shown in FIG. 3 while the vacuum state is kept, and a first cathode 5A is formed on the organic emission layer 4 as shown in FIG. 2c.

As shown in FIG. 3, the vacuum deposition device 20 includes a chamber 11, boat support members 12A and 12B mounted on the bottom surface within the chamber 11, a substrate support member 13 mounted on the upper position within the chamber 11, a shutter 14, a shutter driving portion 15

for controlling a position of a horizontal direction of the shutter 14, an oxygen gas source 16 disposed outside the chamber 11, a gas conduit 18 for supplying an oxygen gas from the oxygen gas source 16 to a gas inlet 17, and a mass flow controller 19 mounted at a point of the path of the gas conduit 18.

5           A boat (a third boat) 21A formed of molybdenum in which an AlLi alloy of 1g is already supplied and a boat (a fourth boat) 21B formed of molybdenum in which an aluminum of 1g is already supplied are disposed and connected to a resistance-heated source (not shown) within the chamber 11 of the vacuum deposition device 20. In addition, the flow amount of oxygen gas introduced  
10   from the gas inlet 17 within the chamber 11 of the vacuum deposition device 20 is controlled by the mass flow controller 19. The third boat 21A is heated by the resistance-heated source when the chamber 11 of the vacuum deposition device 20 reaches a degree of vacuum of  $4 \times 10^{-4}$  Pa or less while the inside of the chamber 11 is evacuated, and the heating temperature is controlled until the  
15   AlLi alloy within the third boat 21A reaches a constant evaporation velocity of 0.4nm/sec. The shutter 14 mounted on the upper position within the chamber 11 is then opened by horizontally moving the shutter to start formation of the AlLi alloy, and is closed at the point of time that the layer thickness of the AlLi alloy reaches about 60nm, thereby terminating the formation of the AlLi alloy.

20           As a result, the first cathode 5A formed of the AlLi alloy is formed on the organic emission layer 4.

Next, in order to contain oxygen at an interface between the organic emission layer 4 and the cathode 5A, an oxygen gas is introduced into the vacuum deposition device 20.



The flowing amount of the oxygen gas, which is introduced from the oxygen gas source 16 of the vacuum deposition device 20 into the chamber 11 through the gas conduit 18 and the gas inlet 17, is controlled at about 10 SCCM (Standard Cubic Centimeter per Minute) by the mass flow controller 19. In this case, a degree of vacuum is  $4 \times 10^{-2}$  Pa. The introduction of the oxygen gas is stopped after about 5 minutes and the inside of the chamber 11 is evacuated until it reaches a vacuum degree of  $4 \times 10^{-4}$  Pa, and the fourth boat 21B is heated by the resistance-heated source, the heating temperature is then controlled until Al within the fourth boat 21B reaches a constant evaporation velocity of 0.4nm/sec, the shutter 14 is then opened to start formation of Al, and is closed at the point of time that the layer thickness of Al reaches about 200nm, thereby terminating the formation of Al.

As a result, a second cathode 5B formed of Al is formed on the first cathode 5A as shown in FIG. 2d. Accordingly, the main element portion composed of the anode 2, the hole transport layer 3, the organic emission layer 4, the first cathode 5A, and the second cathode 5B is formed on the transparent insulating substrate 1. Introducing the oxygen gas is carried out while the vacuum state is kept prior to the formation of the second cathode 5B, so that the time for making the vacuum state when the second cathode 5B is to be formed may be shortened to thereby reduce the process time.

Since the oxygen gas is introduced into the chamber 11 as described above, the oxygen is contained at the interface between the organic emission layer 4 and the first cathode 5A. And this oxygen serves to form a stable level at the interface between the organic emission layer 4 and the first cathode 5A,

which in turn forms the interface between the organic emission layer 4 and the first cathode 5A to be a complete interface. In addition, the second cathode 5B is formed on the first cathode 5A, and the second cathode 5B together with the first cathode 5A serves as a cathode.

5           Next, the substrate 1 is moved into an encapsulation chamber, and for example, the cap 7 formed of glass is employed to be attached to the transparent insulating substrate 1 and encapsulated by means of the UV curing encapsulation resin 6, thereby completing the organic EL device 10 as shown in FIG. 2d. When the encapsulation step is carried out, the UV irradiation for  
10       curing the encapsulation resin 6 is carried out only on the encapsulation resin 6 while the main element portion composed of the anode 2, the hole transport layer 3, the organic emission layer 4, the first cathode 5A, and the second cathode 5B is shielded from the UV irradiation.

          According to the method of fabricating the organic EL device, the  
15       introduction of the oxygen gas for containing the oxygen into the interface between the organic emission layer 4 and the first cathode 5A in order to stabilize the element characteristic prior to encapsulation is carried out while the substrate 1 is disposed within the chamber 11 of the vacuum deposition device 20 and the vacuum state is kept, so that the process time may be reduced.

20           Next, a semiconductor parameter analyzer is employed to measure the rectification characteristic of the organic EL device 10 fabricated by the method as described above. The measurement is carried out by applying a forward voltage and a reverse voltage between the second cathode 5B and the anode 2 of the organic EL device 10. In addition, the emission area of the organic EL

device is 2mm□.

FIG. 4 is a view showing one example of the rectification characteristic of the organic EI device obtained by the measurement, wherein light having a 400nm wavelength is irradiated as the irradiation wavelength ( $\lambda$ ), and the longitudinal axis indicates a current value and the horizontal axis indicates an applied voltage. In this case, when a ratio of a forward current ( $I_f$ ) at a forward applied voltage of 8V and a reverse current ( $I_r$ ) at a reverse applied voltage of – 8V is a rectification ratio ( $I_f/I_r$ ), it can be seen that the reverse current ( $I_r$ ) hardly flows, so that a high rectification ratio of  $4.0 \times 10^8$  and the superior rectification characteristic are obtained.

In addition, FIG. 5 shows a comparative example shows the rectification ratio which is obtained from an organic EL device fabricated by the almost same method as that of the above-mentioned example, wherein introducing the oxygen gas is not carried out after the formation of the first cathode 5A. In this comparative example, as the reverse current ( $I_r$ ) flows when the reverse voltage is applied, it can be seen that a low rectification ratio of  $6.8 \times 10^2$  is obtained and the rectification characteristic is deteriorated.

As can clearly be seen from comparison between FIGs. 4 and 5, the first cathode 5A is formed, and the oxygen gas is introduced to allow the oxygen to be contained into the interface between the organic emission layer 4 and the first cathode 5A, so that the organic EL device may obtain a high rectification ratio as shown in FIG. 4. It is expected that the high rectification ratio results from that the first cathode 5A is formed and the oxygen gas is introduced to allow the oxygen to be contained into the interface between the organic

emission layer 4 and the first cathode 5A so that the interface between the organic emission layer 4 and the first cathode 5A becomes a complete interface as mentioned above.

On the contrary, it is expected that the poor rectification characteristic in the comparative example as shown in FIG. 5 results from that the oxygen gas is not introduced after the first cathode 5A is formed and the oxygen is not contained into the interface between the organic emission layer 4 and the first cathode 5A so that the interface the organic emission layer 4 and the first cathode 5A is not completely formed.

According to the experiment and the analysis of the inventor(s) of the present invention, it is confirmed that the rectification characteristic is enhanced when the cathode is stacked on the organic layer to be in contact with the oxygen whereby the oxygen is introduced into the cathode to reach the interface between the organic layer and the cathode. In other words, it is expected that the oxygen be introduced into defects present at the interface between the organic layer and the cathode to thereby act to lose the impurity level. This corresponds to the state in which the oxygen is buried in defects which occur when the cathode is stacked on the organic layer, which is different from the state that a metal oxide layer is uniformly stacked on the organic layer in advance and the cathode is stacked thereon. In this case, it is confirmed that a superior effect is obtained when the oxygen partial pressure within the vacuum device is in a range of  $2 \times 10^{-4}$  to  $1 \times 10^{-1}$  Pa. FIG. 6 shows the rectification ratios which support the above-mentioned superior effect. And, FIG. 7 shows a comparative example in which the rectification ratio is obtained

when the oxygen partial pressure is selected out of the range of  $2 \times 10^{-4}$  to  $1 \times 10^{-1}$  Pa.

Referring to FIG. 6, No. 1 corresponds to a case of an oxygen partial pressure of  $2 \times 10^{-4}$  and its rectification ratio of  $3 \times 10^8$  is obtained. Similarly, No. 2 corresponds to a case of an oxygen partial pressure of  $2 \times 10^{-3}$  and its rectification ratio of  $2 \times 10^8$  is obtained, No. 3 corresponds to a case of an oxygen partial pressure of  $5 \times 10^{-2}$  and its rectification ratio of  $1 \times 10^8$  is obtained, No. 4 corresponds to a case of an oxygen partial pressure of  $1 \times 10^{-1}$  and its rectification ratio of  $2.8 \times 10^8$  is obtained. All of these rectification ratios are high.

In the meantime, referring to FIG. 7, No. 1 corresponds to a case of an oxygen partial pressure of  $1 \times 10^{-4}$  and its rectification ratio of  $3 \times 10^4$  is obtained. Similarly, No. 2 corresponds to a case of an oxygen partial pressure of  $2 \times 10^{-5}$  and its rectification ratio of  $2 \times 10^4$  is obtained. These rectification ratios are significantly lower than those obtained in FIG. 6, and respective rectification characteristics are also deteriorated.

As can clearly be seen from comparison between FIGs. 6 and 7, a high rectification ratio may be particularly obtained when the oxygen partial pressure is set in a range of  $2 \times 10^{-4}$  to  $1 \times 10^{-1}$  Pa as shown in FIG. 6.

In the case of setting the oxygen partial pressure out of the range of  $2 \times 10^{-4}$  to  $1 \times 10^{-1}$  Pa as shown in FIG. 7, the throughput is deteriorated and an excessive amount of oxygen is consumed, which is not preferable and does not allow the rectification ratio to be higher.

In addition, according to the experiment and the analysis of the

inventor(s) of the present invention, it is confirmed that the rectification characteristic is particularly enhanced when the cathode is formed to have a thickness of about 20nm to 100nm. FIG. 8 shows the rectification ratios which support the above-mentioned superior effect. And, FIG. 9 shows a comparative example in which the rectification ratio is obtained when the cathode is formed to have a thickness out of the range of 20nm to 100nm.

Referring to FIG. 8, No. 1 corresponds to a case of a cathode having a thickness of 20nm and its rectification ratio of  $3.9 \times 10^8$  is obtained. Similarly, No. 2 corresponds to a case of a cathode having a thickness of 40nm and its rectification ratio of  $1.2 \times 10^8$  is obtained, No. 3 corresponds to a case of a cathode having a thickness of 70nm and its rectification ratio of  $1.6 \times 10^8$  is obtained, and No. 4 corresponds to a case of a cathode having a thickness of 100nm and its rectification ratio of  $2.7 \times 10^8$  is obtained. All of these rectification ratios are high.

In the meantime, referring to FIG. 9, No. 1 corresponds to a case of a cathode having a thickness of 10nm and its rectification ratio of  $1.0 \times 10^5$  is obtained. Similarly, No. 2 corresponds to a case of a cathode having a thickness of 200nm and its rectification ratio of  $6.9 \times 10^3$  is obtained, No. 3 corresponds to a case of a cathode having a thickness of 300nm and its rectification ratio of  $4.2 \times 10^2$  is obtained, and No. 4 corresponds to a case of a cathode having a thickness of 500nm and its rectification ratio of  $5.2 \times 10^2$  is obtained. These rectification ratios are significantly lower than those obtained in FIG. 8, and respective rectification characteristics are also deteriorated.

As can clearly be seen from comparison between FIGs. 8 and 9, a high

rectification ratio may be particularly obtained when the thickness of the cathode is set in a range of 20nm to 100nm as shown in FIG. 8.

On the contrary, a high rectification ratio may not be higher when the thickness of the cathode is set out of the range of 20nm to 100nm as shown in  
5 FIG. 9.

When the thickness of the cathode is smaller than 20nm, the cathode has the sparsely spaced thickness, which does not allow the high rectification ratio to be obtained. In addition, when the thickness of the cathode is larger than 100nm, the oxygen is introduced into the cathode so that an amount of the  
10 oxygen reaching the interface between the organic layer and the cathode is reduced and its corresponding rectification ratio is decreased. In addition, the 100nm thick cathode causes a high electrical resistance and a poor display such as brightness non-uniformity, so that it is preferable to form a thick cathode after the cathode is in contact with the oxygen, in other words, a plurality of  
15 cathodes are stacked on the cathode in contact with the oxygen.

The rectification characteristic may be enhanced when the oxygen is in contact with the cathode, however, it is confirmed that the rectification characteristic is a little deteriorated when the step of having the oxygen in contact with the cathode is carried out again in the vacuum state. Due to this  
20 deterioration, it is suggested that there is a possibility of having the molecular type oxygen being absorbed in the defects.

As such, according to the organic EL device of the present embodiment, in the structure where the main element portion composed of an anode 2, a hole transport layer 3, an organic emission layer 4, a first cathode 5A, and a

second cathode 5B is formed on a transparent insulating substrate 1, the oxygen is contained at the interface between the organic emission layer 4 and the first cathode 5A so that a stable level is formed at the interface.

In addition, according to the method of fabricating the organic EL device of the present embodiment, the transparent insulating substrate 1 where the anode 2, the hole transport layer 3, the organic emission layer 4, and the first cathode 5A are already formed is disposed within the vacuum deposition device 20, and an oxygen gas is introduced while the inside of the vacuum deposition device is kept in a vacuum state, and the oxygen has a layer formed at the interface between the organic emission layer 4 and the first cathode 5A, so that the process time may be reduced.

Accordingly, the throughput for the device fabrication may not be lowered and a high rectification ratio may be obtained.

Preferred embodiments of the present invention have been disclosed herein, however, various changes in form and details may be made without departing from the spirit and scope of the present invention as set forth in the following claims. For example, ITO is employed for the anode which is formed on the transparent insulating substrate, however, it is not limited to ITO when it is formed of a transparent conductive material, so that other electrode materials such as  $\text{SnO}_2$  may be employed. In addition, not only an AlLi alloy but also other electrode materials such as Al, MgAg may be employed for the cathode. In addition, not only  $\alpha$ -NPD but also Bis(d(p-tril)aminophenyl)-1,1-cyclohexane, N, N'-diphenyl-N, N'-bis(3-methylphenyl)-1,1'-biphenyl-4,4'-diamine, N, N'-diphenyl-N-N-bis(1-naphthyl)-(1, 1'-biphenyl)-4,4'-diamine, starbust type



molecule or the like may be employed for the hole transport material.

In addition, formation of the main element portion composed of the anode, the hole transport layer, the organic emission layer, the first cathode, and the second cathode is described in the embodiment, however, when the interface between the organic emission layer and the cathode is formed, the present invention is not limited to this structure but may be applied to another main element portion composed of an anode, an organic emission layer, and a cathode. In addition, in the case of the structure having a plurality of cathodes, it is required that an amount of oxygen contained in a first cathode in contact with the organic layer including at least the organic emission layer among the plurality of cathodes is larger than that in the rest cathodes including a second cathode not in contact with the organic layer among the plurality of cathodes.

According to the organic EL device of the present invention as mentioned above, the oxygen is contained at the interface between the organic emission layer and the cathode in the structure where the main element portion having the interface between the organic emission layer and the cathode is formed on the transparent insulating substrate, so that a stable level is formed at the interface.

Furthermore, according to the method of fabricating the organic EL device of the present invention, the transparent insulating substrate where the main element portion having the interface between the organic emission layer and the cathode are already formed is disposed within the vacuum device, and an oxygen gas is introduced while the inside of the vacuum device is kept in a vacuum state, and the oxygen has a layer formed at the interface between the

organic emission layer and the cathode, so that the process time may be reduced.

Accordingly, the throughput for the device fabrication may not be lowered and a high rectification ratio may be obtained.

5           Although the present invention has been described with reference to certain exemplary embodiments thereof, it will be understood by those skilled in the art that a variety of modifications and variations may be made to the present invention without departing from the spirit or scope of the present invention defined in the appended claims, and their equivalents.

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#### **BRIEF DESCRIPTION OF THE DRAWINGS**

FIG. 1 is a cross-sectional view showing a structure of an organic EL device in accordance with one embodiment of the present invention;

15           FIGs. 2a to 2d are process flow diagrams showing a method of fabricating the organic EL device in a process order;

FIG. 3 is a schematic view showing a structure of a vacuum deposition device which is used for main steps of the method of fabricating the organic EL device;

20           FIG. 4 is a view showing the rectification characteristic of the organic EL device;

FIG. 5 is a view showing the rectification characteristic of the comparative example of FIG. 4;

FIG. 6 is a view showing a rectification ratio obtained when oxygen partial pressure within the vacuum device is changed in accordance with the

experiment and analysis of the present invention;

FIG. 7 is a view showing a rectification ratio of the comparative example of FIG. 6;

FIG. 8 is a view showing a rectification ratio obtained when a thickness  
5 of a cathode of an organic EL device is changed in accordance with the experiment and analysis of the present invention;

FIG. 9 is a view showing a rectification ratio of the comparative example of FIG. 8;

FIG. 10 is a schematic view showing a structure of a typical organic EL  
10 device; and

FIG. 11 is a schematic view showing a structure of an organic EL device in accordance with the prior art.